HEAT DISTRIBUTION IN A FOOS' GAS ENGINE

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GE
TOWNE
378.748
POS 1897.3
REFERENCE

2537
THESIS
990

Heat Distribution

in a

Foos' Gas Engine.

by

Dunbar H. Bradley.
Irving A. Chandler.

Bradley & Chandler '97

Gas Engine, Foos.

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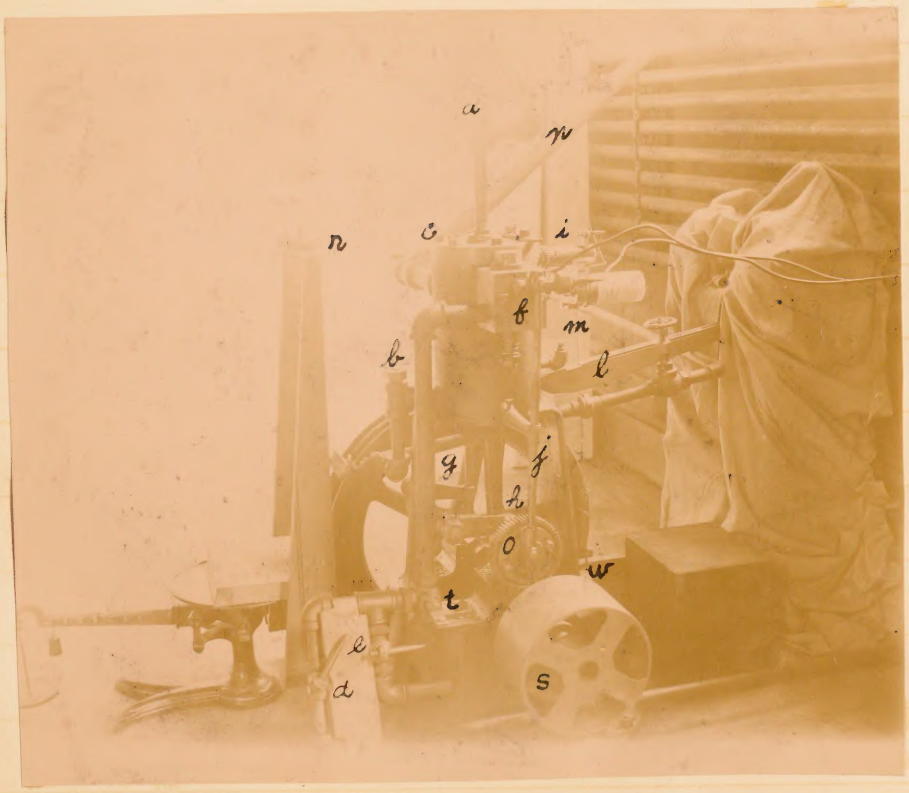


Readings During Test

Time	Temp. of Water inflow	Temp. of Water outflow	Temp. Air	Temp. Gas	Temp. Exhaust	Barometer.	Explosion Counter	Brake Reading	Jacket Water	Time at mark of Gas Meter.
1-54-05	80	170	83	83.5	560	30.002"	04199	19 lbs.	160.75	1-54-05 1-56-15 1-58-25 2-0-35
2-5-	76	175	83.5	84	580			"		2-2-45 2-4-55 2-7-05 2-9-15
2-15-	79	184	84	85	574			"		2-11-30 2-13-40 2-15-50
2-25-	81	195	83.5	85.5	577			"		2-18-0 2-20-5 2-22-15
2-32-0	82	196	83.5	84	578		11449	"	209.0	2-24-25 2-26-35 2-28-45 2-30-55
0-36-55	79.6	184	83.5	83.8	574	30.002"	7250	19	48.25	34 cu. ft.

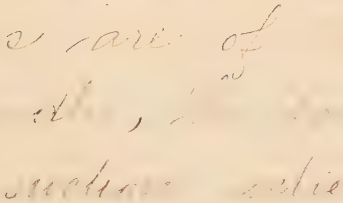
2

Exaust Gas Analysis

Original Volume	After using KOH	Pyro.	$CuCl_2$	Percentage of CO_2	O	CO
100.0	93.3	93.2	90.2	6.7	0.1	3.0
100.0	92.8	92.8	89.7	7.2	0.0	3.1
100.0	90.7	90.7	89.1	9.3	0.0	1.6
100.0	91.8	91.6	89.0	8.2	0.2	2.6
100.1	94.8	94.1	87.6	5.3	0.7	6.5
				7.34	0.2	3.36

The sum of these three percentages is 10.90 leaving 89.1 % for N.

The clearance volume of the engine was determined by filling the space above the piston, when at its highest point, with a known weight of water. The quantity poured in was 12 3/4 ozs. which equals 22.1 cu. in.



the oil cups at (c) and (d).

The exhaust has its trough
the pipe (m) and the muffler.
In the exhaust pipe at (n) is
placed the oil cup in which
was a mercury thermometer, read-
ing to 600° F., to determine the
temperature of the exhaust gases.

The governor is controlled
by means of a centrifugal throw
governor on the belt wheel (s)
which operates a balanced throttle
valve (t).

To operate the indicator a steel
rod is attached to the piston and
extends downward through the
stuffing box; the lower end
of this rod is connected to the
lever (k) which is suspended
at the other end, by a steel rod,

from a fixed point. A piece of braided wire (m) is attached to the drum of the [illegible] and passes down through a hole in the wooden lever (l), being fastened to a weight (w) near the floor. When the weight is raised by [illegible] the wire (m) comes up against the lever (l) and throws the [illegible] end [illegible].

The explosions are accomplished by an electric spark obtained from three storage cells and coils with a spark coil.

The secondary coils are connected to the [illegible] and consequently explosions the number of explosions. The connections are [illegible].

The radius of the [illegible] to be determined by the length of the [illegible] and [illegible] and then to account for the [illegible] of the heat as [illegible] in the enclosed piece packed under cork that would with [illegible]. The packed [illegible] with a piece of [illegible] cooked [illegible] and also having the working stroke.

The first observation was to find the heat that would be generated by the [illegible] of the [illegible].

By analysis the [illegible] was found to be as follows

	% volume	Molecular weight	% weight	Heat Equivalent	
CO_2	0.7	22	.02311	0	0
CO	7.1	14	.14914	4476	667.6
C_2H_4	6.3	14	.13233	21470	2836.5
O	0.9	16	.02160	0	0
CH_4	31.4	8	.37689	23851	8989.0
H	42.5	1	.06377	62100	3960.0
N	11.1	14	.23316	0	0
			1.00000		16 453.1

In the first column is the percentage volume, in the second the molecular weight, in the third the percentage by weight, in the fourth the heat equivalent, and the fifth is the product of the third and fourth columns; the sum of the numbers in the fifth column is the heat equivalent of one pound of the gas

Next we found the "R"

of the gas, by multiplying the percentage weights found by the "C_p" and then by the "C_v"; the difference of the sum of these products multiplied by .778 gives the "R" sought for.

The work is as follows.

	% weight	C_p		C_v	
CO_2	2.311	.216	.505	.171	.395
C_2H_4	13.233	.404	5.346	.332	4.393
O	2.160	.217	.469	.155	.335
CO	14.914	.245	3.803	.173	2.580
CH_4	37.689	.593	22.350	.467	17.601
H	6.377	3.409	21.739	2.406	15.343
N	23.316	.244	5.687	.173	4.034
			59.901		44.681

$R = (C_p - C_v)\,778$

$= (.59901 - .44681)\,778 = 118.41$ ft. lbs.

The same operation was carried out with the exhaust gas, considering it as free from moisture, afterwards getting the "R" for the gas and moisture together.

	% volume	Molecular weight		% weight	C_p	
CO_2	7.34	22	161.5	.108685	.216	.023476
O	.20	16	3.2	.021535	.217	.006673
CO	3.36	14	47.0	.031630	.245	.007747
N	89.10	14	1245.4	.838150	.244	.204515
			1457.1	1.000000		.242413

"C_p" of gas = .242413

	% weights	C_v	
CO_2	.108685	.171	.018585
O	.021535	.155	.003338
CO	.031630	.173	.005472
N	.838150	.173	.145000
	1.000000		.172395

"C_v" of gas = .172395

$C_p - C_v = .242413 - .172395 = .070018$

$K = .070018 \times 778$

The water formed by the combustion of the gas was next found as follows

	% weight	wt. of gas per hour		Water Formed
C_2H_4	.13233	1.7888	$\frac{36}{28}$	0.30434
CH_4	.37689	"	$\frac{36}{16}$	1.51690
H	.06377	"	9	1.02665
				2.84789

The first column is the percentage weight of the gases capable of forming water, the second is the weight of gas used per hour, the method of determining which is shown later; the third is the proportion of water it will form from the "H" in the gas; and the sum of the quantities in the fourth is the weight of

water formed per hour.

To determine the weight of one cubic foot of the air we assumed the gas to be half saturated, because its temperature was higher than when it passed through the wet meter. We found from Carhart's steam table that the pressure at 73.1° equals 0.565# and its weight 0.001736 pounds per cubic foot. For half saturation these are 0.287 and .000868. The barometer was 30.002 inches, corresponding to a pressure of 14.743 pounds. Then 14.743 − 0.287 = 14.456 = pressure of the gas. Therefore the weight of one cubic foot of gas equals $p \div RT$

$$\text{Specific wt.} = \frac{14.457 \times 144 \times 1}{18.41 \times 514.3} = 0.03228$$

Since the meter registered 3.1 cubic feet in 36.83 minutes we find the weight per hour to be

Weight dry gas per hour $= \frac{60}{36.83} \times 34 \times .03228$

$= 1.7838$ pounds

Weight moisture per hour $= \frac{60}{36.83} \times 34 \times .000868$

$= .0479$ pounds

Then assuming the temperature of the gases in the cylinder at the end of the suction stroke to be 190°F. (This is 6° above observed temperature of gases at outlet), and finding the volume swept out by the piston per hour, we can find the pressure of the gas and moisture separately

The volume of displacement of the piston per hour is

$$\frac{34}{37} \times \frac{62.83}{1728} \times 7250 \times \frac{60}{36.83} = 394.4 \text{ cu. ft.}$$

$\frac{34}{37}$ is the proportion of the stroke during which the piston is sucking.

$$p = \frac{RT \times wt.}{V} = \frac{118.41 \times 650.7 \times 1.7488}{394.4} = 2.7834 \#$$

for the gas and for the moisture it equals

$$p = \frac{.111 \times 778 \times 650.7 \times .018}{394.4} = 0.0475 \#$$

The pressure in the cylinder during the sucking stroke was scaled from the indicator cards and found to be 11.7438 pounds. Then $11.7438 - (2.7834 + 0.0475) = 8.9129$ is the sum of the pressure of the dry air and moisture in the air.

From the weather bureau

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[illegible] for the 2nd day (April 19th) we found that their [illegible] corresponded to the [illegible] of the last [illegible] as follows.

At a temperature of 69°F. and a barometer pressure equivalent to 14.784 pounds, the humidity was 0.40

From Keenan & Keyes steam tables the pressure of this temperature is 0.3481 and at 40% saturation this is .40 × .3481 = .139 and therefore the pressure due to the dry air is 14.784 − .139 = 14.645 #

Weight of air per cu. ft. = p ÷ R'T'

$$= \frac{14.645 \times 144}{53.37 \times 519.7} = 0.08603$$

From Kent-Ley's tables the weight of steam at 69°F and .40

saturation is .00438 pounds per cubic foot.

Therefore the ratio of weight of water to weight of saturated air is

$$= \frac{.08603}{.00438}$$

Now let p_a = pressure of air alone.
" " p_m " " " moisture in air

then we have

$$\frac{p_a}{p_m} = \frac{\frac{lbs_a \times Kal}{V}}{\frac{lbs_m \times Kal}{V}} = \frac{lbs_a}{lbs_m} \times \frac{K_a}{K_m}$$

$$= \frac{.08603}{.000438} \times \frac{53.37}{.111 \times 778} = 121.39$$

$\therefore p_a = 121.39\, p_m$

but $p_a + p_m = 8.9129$

$$121.39\, p_m + p_m = 8.9129$$

$$p_m = \frac{8.9129}{122.39} = .07218$$

and

$$p_a = 8.9129 - .07218 = 8.84072$$

Now we have sufficient data to find the weight of air and moisture in the air per hour.

$$\text{Weight of air} = \frac{p \times V}{R\,T} = \frac{8.8707 \times 144 \times 394.54}{53.37 \times 650.7}$$

$$= 14.466 \text{ pounds}$$

Weight of moisture in the air

$$= 14.466 \times \frac{.000438}{.08603}$$

$$= 0.07365 \text{ pounds}$$

The pressures and weights of the substances in the cylinder just before compression are as follows.

	Weights	Pressures
Air per hour	14.4660	8.84072
Moisture in air per hour	0.0737	0.07218
Gas per hour	1.7888	2.78340
Moisture in gas " "	0.0480	0.04750
	16.3765	11.74380

Weight moisture in entering air = 0.0737
" " " " gas = 0.0480
" " due to combustion = 2.8479
Total weight moisture in exhaust = 2.9696

As the total weight of mixture passing through engine per hour is, as shown on previous page, 16.3765 lb.
And wt. moisture in exhaust is 2.9696 "
Then wt. dry gas in exhaust is 13.4069 "

As the engine exhausted to the atmosphere, the exhaust took place at constant pressure and as we have previously determined the specific heat at constant pressure we are now able to determine the amount of heat carried out through the exhaust.

Heat in dry exhaust gas due to rise of temperature above that at entrance

$= C_p \times wt \times (T_{ex} - T_{ent.})$ B.T.U.

$= .242413 \times 13.4069 \times (574 - 83.6) =$ 1593.8

Heat in superheated moisture due to rise of temperature

$= .4805 \times 2.9696 \times 490.4 =$ 699.7

There is also a certain amount necessary to vaporize the water due to combustion. This is equal to the "r" of steam at atmospheric pressure (14.746#)

$= r_{14.746} \times wt. = 965.7 \times 2.8479 =$ 2750.2

Available heat due to unconsumed CO in exhaust gas $= .03163 \times 13.4069 \times 4476 =$ 1898.1

Total heat lost in exhaust = 6941.8

The next loss to be investigated is that by means of the water jacket. This quantity is the "q" at exit temperature minus the "q" at entrance temperature times the weight of water per hour

$= Wt\,(q_{184} - q_{49.6})$

$= 78.595 \times 104.45 =$ B.T.U. 8209.3

The heat indicated as work is next to be calculated. To do this it is first necessary to determine the indicated horse power and then find its equivalent in heat units per hour. From the cards the average mean pressure was found to be = 28.974 #

and the number of explosions per minute = 196.833

therefore the

$$I.H.P. = \frac{28.974 \times 5'' \times 3.1416 \times 16 \times 196.833}{12 \times 33000}$$

$$= .9044$$

The equivalent of this in heat units is equal to $\frac{.9044 \times 33000 \times 60}{778}$

$$= \underline{\quad} \quad \text{£}306.1$$

Having now calculated all the heat losses possible there now remains to determine the number of heat units supplied to the engine and then to form the heat balance sheet. The heat supplied is found by multiplying the weight used per hour by the

calorific power per pound; both of these quantities have already been determined, therefore the heat supplied equals

$1.7888 \times 16450 = 29426$

The balance sheet is as follows.

Total heat supplied	29426	
Heat escaping through exhaust		6941.8
" " in jacket water		8209.3
" indicated as work		2306.1
" unaccounted for		11968.8
	29426	29426.0

The percent unaccounted for equals

$\frac{11968.8}{29426} = 40.67\ \%$

This large percentage is attributed to the following things.

First a certain unknown amount

is due to radiation, but this is comparatively a small amount probably between two and five percent.

The next thing to be considered is that the thermometer in the exhaust pipe does not register the highest temperature of the exhaust gases, and thus the quantity of heat escaping through exhaust is probably much higher than the quantity computed.

And lastly the thing which is supposed to involve the greater part of this loss is the leakage around the piston. When starting the engine the hissing of the escaping gas was distinctly heard while the

charge was being compressed previous to explosion, and the instant after explosion the hissing was more audible.

This however apparently ceased as soon as the engine reached its proper speed

Constants

Clearance	22.1 cu in
Spe reading of brake	8/16 lbs.
Stroke	5"
Diameter cylinder	4"
Brake arm	7 3/4"
Volume of piston displacement	62.83 cu in
Ratio of $\frac{\text{Clearance}}{\text{Displacement}}$	.351

Our authority for the values of "Cp" and "Cv" used was "The Gas Engine" by Clerk.

And for the heat equivalents of the various gases for formed we are indebted to "Engineering Chemistry" by Stillman.

The cylinders per minute at
speed $\frac{1250}{36.833}$ = 196.833

Revolutions per minute = 393.67

Inches water per horse power

$$\frac{18.25 \times 60}{36.833} = 178.575 \text{ ft}$$

Gas used per horse in cubic feet
per hour $= \frac{24 \times 60}{36.833} = 55.853$

The brake horse power is as follows

$$= \frac{9.75 \times 2 \times 3.1416 \times 393.67 \times 10.94}{12 \times 33000} = 0.66627$$

Therefore the mechanical efficiency is equal to

$$\frac{BHP}{IHP} = \frac{.66627}{.9044} = 73.67\ \%$$

The efficiency of transformation is equal to the heat units equivalent to the indicated power divided by the total heat units supplied per hour

$$= \frac{2306}{29462} = 7.84\ \%$$

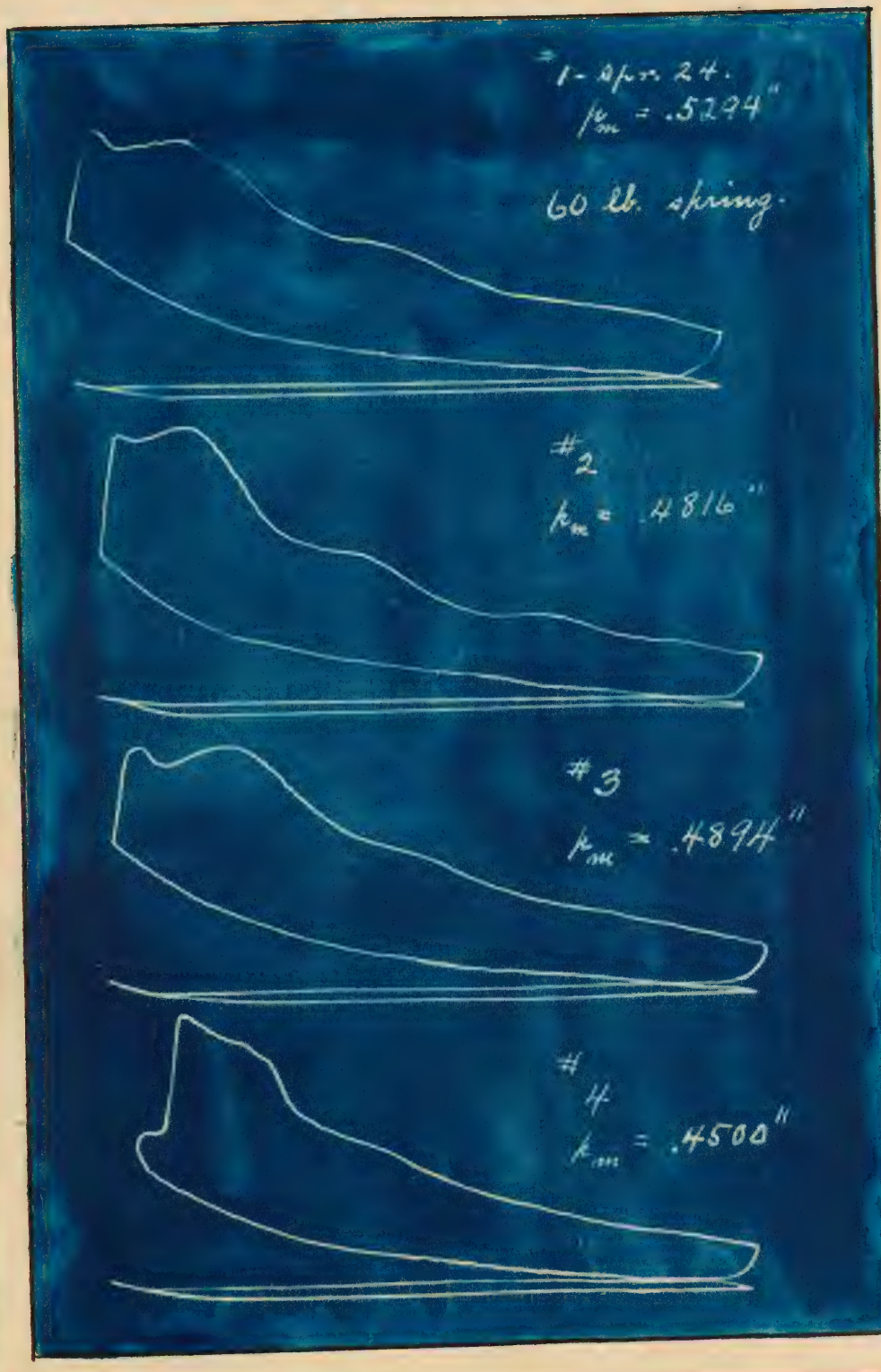
The actual efficiency is the product of these two i.e. the brake power divided by total heat supplied per hour

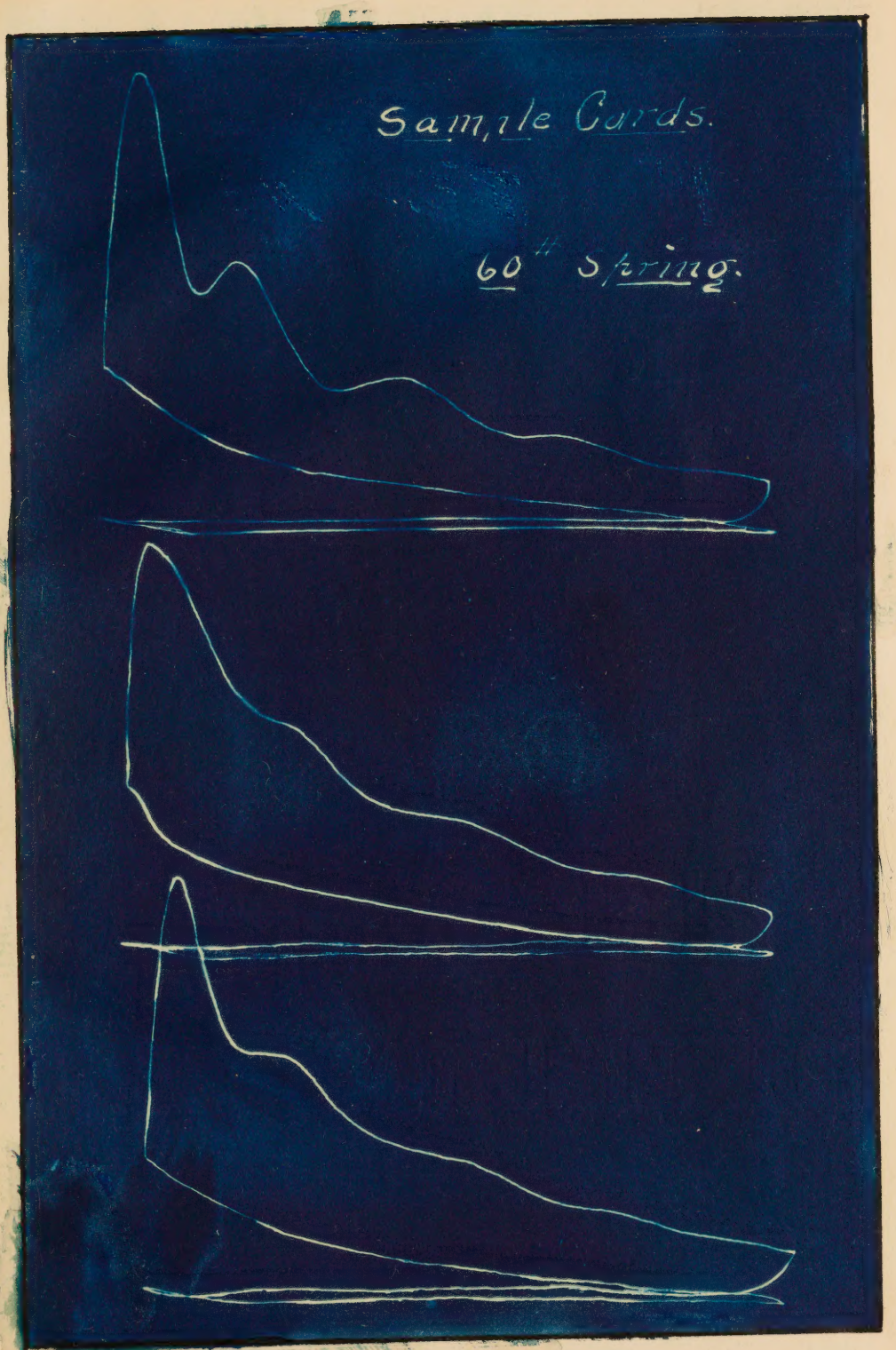
$$= 5.775\ \%$$

Recapitulation

No. of test.	I	II
Indicated Horse power	.9044	.97529
Brake horse power	.66627	.6992
Gas used per hour (cu ft)	55.383	16.207
" " " " (pounds)	1.7888	1.5035
Water jacket per hour "	78.595	116.38
Explosions per minute	196.833	197.167
Revolutions " "	393.67	394.33
Mechanical efficiency	73.67	71.67
Belt "	5.775	10.00
Heat converted for (%)	10.675	22.33

The second test confirms the values of the second test which were worked out in the same way as the first test.


#1 - Apr. 24.
k_m = .5294"
60 lb. spring.
#2
k_m = .4816"
#3
k_m = .4894"
#4
k_m = .4500"


Sample Cards.
60# String.

3 1198 03072 7809
N/1198/03072/7809X

3 1198 03072 7809
N/1198/03072/7809X